VEGETATION ON GIBBSITIC SOILS IN HAWAII

J. C. Moomaw and M. Takahashi

Studies of the vegetation of an area of highly aluminous soils on the island of Kauai were initiated early in 1958. The soils were being considered by several aluminum companies as a commercial source of bauxite and the studies on rehabilitation of land denuded by strip mining were undertaken at the request of the then Territorial Legislature by the Hawaii Agricultural Experiment Station.[1] The purpose of the studies was to accumulate the ecologic, soil, and agricultural information that would enable the Legislature to enact suitable and just laws governing the reclamation of the mined area following removal of the mineral. It is the purpose of this paper to report studies of the initial vegetation of the reclamation study site made before the simulated mining and reclamation studies were begun. These studies represent the basic floristic and ecologic data with which comparisons of the reclamation treatments and results will be made. Coöperation in parts of the research was provided by several other departments of the Territorial government, especially the Board of Commissioners of Agriculture and Forestry, the Territorial Commissioner of Public Lands, and the B. P. Bishop Museum. Voucher specimens of the plants collected were deposited in the Bishop Museum and retained for study in the University of Hawaii Department of Agronomy and Soil Science.[2]

The site of the major investigations is an area of about 2500 acres located six miles WSW of Kapaa, Kauai, in the Wailua Game Refuge and adjacent lands. (The elevation varies from 500 to about 2000 feet.) Brief reference will be made to areas on Maui and Hawaii that were briefly examined and from which plant collections were made for determinations of tissue aluminum levels (Moomaw *et al.*, 1959).

Major studies of the vegetation of aluminous soils have been made in Australia–New Guinea (Webb, 1954) and in Jamaica (Howard & Proctor, 1957). In the Australia–New Guinea flora, 69 of 1154 dicotyledonous species examined were classified as accumulators of aluminum, as were 11 of 87 pteridophytes and *Lycopodium*. No monocotyledons or gymnosperms were so classified of 69 and 14 species respectively examined. The information developed by Webb in this study was used primarily for taxonomic deductions concerning the flora and the evolutionary status

[1] Published with the approval of the Director of the Hawaii Agricultural Experiment Station, University of Hawaii, as Technical Paper No. 483.

[2] Appreciation is expressed to Marie C. Neal, Curator of the B. P. Bishop Museum Herbarium, and to E. Y. Hosaka, Hawaii Agr. Extension Service, for help with the identification of some of the specimens.

of its members and secondarily for biochemical and ecologic discussions. Aluminum accumulating plants were never found on alkaline soils but were restricted to leached, acid soils from a variety of parent materials. Most of the species were inhabitants, with exceptions, of the closed mesic forest formation in eastern Australia which is in accord with the work of others (Chenery, 1948, 1949), who have observed the high frequency of aluminum accumulator species in the floras of the moist tropics. Webb states aluminum accumulators to be striking examples of what Crocker (1952) calls "pedogenetically effective biotypes" in that they favor laterization by the accumulation and retention of aluminum in the surface layers of the soil and in the litter and organic matter. Evidence from Webb (1954) and from Chenery (1948, 1949) indicates that accumulation is relatively rare in the monocotyledons but the information from Hawaii's gibbsitic soils given by Moomaw *et al.* (1959) shows substantial levels of the element in the dominant grasses, (especially *Paspalum orbiculare*), several other grasses, and the ground orchid *Spathoglottis plicata.*

The extensive work of Howard and Proctor in Jamaica (1957) led to conclusions that the Jamaican bauxite soils supported few species of aluminum accumulators and that the bauxite flora consisted of plants unaffected by aluminum and tolerant of its presence. They found no species characteristic of bauxite soils and did not find any species on adjacent soils that would not grow in the bauxite deposits. Their examination of a large flora in an area of active mining included successional studies on fallow mining pits and replanting plots with woody and pasture species.

GEOLOGY AND SOILS

The parent rocks of the Wailua Game Refuge are part of the Koloa volcanic series which flowed from vents in the mountain range to the north (MacDonald *et al.*, 1954) and the soils derived from these low-silica melilite and nepheline basalts have been described by Sherman (1958) and Cline *et al.* (1955) as belonging to the Aluminous Ferruginous Latosol and Ferruginous Humic Latosol great soil groups. The principal soil series in the area are the Halii, Puhi and the Haiku. The Halii series, in the Honolua family, is described by Cline *et al.* (1955) as being three to four feet in depth with dark brown, strongly granular, gravelly, silty clay at the surface grading into reddish and yellowish-red, blocky, silty clay at the depth where weathered rocks that have retained most of their original structure are frequently encountered. The soils are strongly acid (pH 3.5 to 5.0) and generally occur on long, smooth, narrow ridges of gentle (3–8%) slope but with steep-sided (40–50% slope) narrow gullies between them.

The chemical weathering of these soils from their porous, fine-grained parent rock is stated to be typical of many of the bauxite areas of the world and has been exceedingly rapid (Sherman, 1958; Mohr & Van Baren, 1954) because: (1) easily soluble minerals are present that are relatively free from combined silica and almost totally free from quartz;

(2) the topographic position, high effective rainfall at the higher elevations, combined with the high infiltration rate, free circulation and lateral movement of the percolating water favor the reduction and leaching of the iron oxides; (3) the humus of the forest floor produces an acid soil solution (Sherman & Kanehiro, 1948) which hastens the leaching process; and (4) a long period of chemical weathering has brought about the decomposition of silicates and the subsequent desilication of the weathering zone. The product of this intense and lengthy weathering process is a group of strongly leached soils depleted of bases and silica (0–5% SiO_2) with high concentrations of iron (25–60% Fe_2O) and alumina (20–50% Al_2O_3) and with at least small amounts of titanium (3–6% TiO_2). The principal mineral in the clay fraction developed under these conditions has been identified as gibbsite (Sherman, 1958).

Much evidence of mineral deficiency, especially of phosphorus, is observed in the vegetation. The surface soils are low in total bases but high in total nitrogen and organic matter. Physically the soils are classed as clays but do not in general display the physical properties usually associated with clays. Even when moist the soils present no physical problem in tillage operations.

THE CLIMATE

The mean annual rainfall has not been accurately measured on the main research site but it is known from adjacent areas to vary between 50 and 150 inches and to be well distributed. In general, the mean rainfall is greater than three inches per month and more than five inches per month during seven to twelve months of the year, with more than ten inches falling during two to seven months. The effectiveness of the rainfall is high and the soils are dry for only a few months in the lower areas. The rainfall exceeds evaporation and transpiration, especially during the winter months, partly because of a high degree of cloudiness. Relative humidity is high. Data for the nearest long-term weather station, Kapaa Stables, are given in TABLE I.

The average air temperature at sea level is about 73° F. in this zone, which is two or three degrees lower than that in the dry regions and, of course, it decreases with elevation. Extreme temperatures seldom exceed 90° F. or fall below 55° F. A long-term record of temperature for the northeast shore of Kauai is shown in TABLE I.

Wind blows almost constantly from the northeast at 10 to 20 miles per hour and exerts a drying influence on the exposed ridge-tops but frequently brings the trade showers to these same parts of the landscape. Hurricanes have been known in the area only recently and wind velocities of 75 or 80 miles per hour have been recorded. In the Islands the trade winds diminish and sometimes fail completely during and just after the autumnal equinox.

Daylength at 21° N. Latitude varies about 2.7 hours from June to December.

TABLE I. **Mean Monthly Temperature and Rainfall Data for Nearby Stations** (Weather Bureau, 1959).

STATION	Kapaa Stables	Kealia
ELEVATION	175 feet	9 feet
YEARS OF RECORD	18	47
	PRECIPITATION	TEMPERATURE
January	6.36 inches	70.9° F.
February	5.91	71.1
March	6.14	71.6
April	4.47	73.2
May	2.64	75.0
June	2.03	77.1
July	2.46	78.1
August	2.82	78.9
September	2.41	78.6
October	4.81	77.4
November	5.95	74.9
December	6.21	72.7
Annual	52.21 inches	75.0° F.

LAND USE AND HISTORY

At present, most of the land in the Honolua soil-family is used for either pasture or forest production. In neither case is the production potential high. The forest is composed mostly of *Meterosideros collina* ssp. *polymorpha* (ohia lehua) which is not of merchantable size. The forage produced is considered to be of inferior quality because of apparent low dry-matter production, low palatability, and probable mineral deficiencies. Shrubby weeds are a constant source of trouble in these areas. There is evidence that applications of lime and fertilizer will greatly improve production and nutritive value of the forage. The pastures are generally used for breeding herds and not for fattening cattle except when improved species such as *Digitaria decumbens* (Pangola grass), *Pennisetum clandestinum* (Kikuyu grass), or *Pennisetum purpureum* (Napier grass) have been planted. Paspalums, especially *P. conjugatum*, are naturalized pasture species of fair value. Very little land area of this type is cultivated at present, the high degree of cloudiness limiting sugar-cane production and the wetness restricting its use for pineapple culture. Since the climate is continually moist, the control of diseases, insects, and weeds is extremely difficult. Little of the area is used for vegetable crops or fruit production but current research shows that this can be changed in many cases by improving fertility.

The land-use history of the Game Reserve of Kauai is one of hard use and abuse with a relatively recent attempt at reclamation through reforestation and game-food planting. The primeval vegetation was almost certainly forest but the composition of the forest is difficult to reconstruct after nearly 200 years of agricultural use by European and American settlers. The 900–1000 years of Hawaiian settlement had relatively little effect on this area since their settlements were normally confined to the beaches and the broad open valleys at low elevation. No remnant of terraces or native artifacts was encountered in the Game Reserve and such important native food plants as breadfruit, cooking banana and *Alocasia macrorrhiza* (ape) were absent.

The three major phases in the history of the Hawaiian flora were: (1) the arrival of the Hawaiians with their food plants and limited cultivation; (2) the introduction of European agriculture, forestry (especially the sandalwood trade) and cattle about 1790; and (3) the continued introduction of useful and weedy plants that have readily naturalized in the Hawaiian Islands. Especially the second and third of these influences have had a major effect on the Hawaiian vegetation in all ecologic zones and have led to replacement of the indigenous vegetation to a major degree by exotic species (Degener, 1932–date; Neal, 1948).

The vegetation of the Game Refuge of Kauai is classed in zone D_2 by Ripperton and Hosaka (1942) and was originally forested. The vegetation is dominated by *Metrosideros collina* subsp. *polymorpha* (ohia lehua) which is associated with *Acacia koa* (Hawaiian koa) and *Psidium guajava* (guava) in most places. Ferns such as *Dicranopteris linearis* (false staghorn), *Sadleria cyatheoides* (amaumau), *Nephrolepis exaltata* (Boston fern), and the tree fern *Cibotium chamissoi* are frequent. *Pandanus sp.* (hala) and *Aleurites moluccana* (kukui) are abundant in some areas and *Stachytarpheta cayennensis* (joee) is a weed of nearly universal occurrence. Open areas are dominated by grasses, sedges, herbs and several of the smaller ferns mentioned above. *Paspalum conjugatum* (Hilograss), *P. orbiculare* (ricegrass), *Setaria geniculata* (yellow foxtail) and a few others are found, and *Axonopus affinis* (carpetgrass) and *Sporobolus capensis* (rattail grass) are becoming more widespread. *Cyperus spp.* (sedges), *Centella asiatica* (Asiatic pennywort), *Mimosa pudica* (sensitive plant), and *Cuphea carthagenensis* (tarweed) are among the usual herbs.

The original forest on the reclamation site was probably a *Metrosideros* overstory with the tree fern *Cibotium chamissoi* either as the ground cover or at least well represented in the understory. The tree cover was probably relatively open on the ridge-tops. Whether the *Acacia koa* or *Santalum freycenetianum* (sandalwood) were ever represented here cannot be determined from present evidence, but is unlikely. The *Acacia* may have extended to this low elevation at one time. *Aleurites moluccana* (kukui) and *Eugenia malaccensis* were dominant in the valley-bottoms and drainages, but during the past hundred years these have been largely replaced by the more aggressive *Psidium guajava*, introduced in 1835. They show evidence of regeneration as does the *Metrosideros* on higher slopes.

The date of the first destruction of the forest cover on the Game Refuge is difficult to place but it can be said with certainty that since World War I the area has been repeatedly burned and at least lightly grazed. From 1918 to 1938, a major part of the area was leased as public grazing land, prior to which it had been in the Forest Reserve. There is no evidence of pasture improvement practices other than fencing, and it is known that the carrying capacity for livestock was very low. Species of improved pasture grasses and legumes are absent.

In 1939 the Wailua Game Refuge was created and management passed to the Division of Fish and Game of the Board of Agriculture and Forestry. Grazing was immediately prohibited and attempts were made to improve the cover and food supply for introduced species of game birds. During World War II, the Refuge was turned over to the military for a training area and was used for maneuvers, bivouac, and as an artillery range. Coral sand was brought in for camp sites and many of the ridges were travelled by military vehicles. The higher elevations were used as the impact area for an artillery range, which caused repeated fires. The lower, drier parts of the Refuge were much more easily fired than the higher parts but even on the slopes of Mount Waialeale to the west, where the annual rainfall probably exceeds 250 inches, the burned snags of *Metrosideros* trees of 18-inch diameter can be seen.

The area of study is traversed by an irrigation-ditch system involving a series of tunnels and ditches in some of the valleys but no direct influence on the vegetation is involved.

About ten years ago, after the end of the war, the Board of Agriculture and Forestry instituted a trial planting on a part of the area involving macadamia nut, Norfolk Island pine, and the variegated *Pandanus variegatus* (hala). Some of the planted trees have survived and are making slow growth. On a small plot of about an acre, the Board planted *Cajanus cajan* (pigeon pea) after plowing, liming with 500 pounds of crushed coral and fertilizing with 150 pounds of superphosphate per acre. The effect of this treatment is still visible on aerial photographs and can be seen on the ground from a distance of about a mile.

It is also interesting to conjecture on the role of wild goats in the destruction of native forest in this area and its subsequent displacement by introduced species.

VEGETATION OF GIBBSITIC SOILS

Methods

After an initial reconnaissance and examination of aerial photographs, the immediate surroundings of the test area were analyzed by examining a series of seventeen 100-foot line transects. Seven of the transects were oriented parallel with the center-line of the main ridge and on it, two were transverse transects on the ridge top, and eight of the transects were in pairs on the generally north- and south-facing slopes about one-third of the slope distance from the ridge-top and the valley-bottom respectively.

On each transect, *cover* was estimated on 50 two-square-foot plots evenly spaced along the line. Cover was estimated directly for each species present to the nearest five per cent and *frequency* was calculated from the cover data. Cover and frequency are commonly used ecologic measures of the importance of species in the plant community and of their distribution and dominance (Braun-Blanquet, 1932; Brown, 1954).

As used in this study, cover is best defined as the percentage of the total soil area covered by living plant material when it is projected downward into the plane of the soil surface from its natural growing position. It is always taken as the maximum spread of the plant involved, ignoring minor discontinuities in the crown or aerial portions. Since the objective of the method is to give a measure of the relative dominance of the species among its competitors, foliar spread is accepted as a good relative measure of root spread which is also an important factor in competitive domination.

Frequency is simply the percentage of the total number of plots in which the species occurred. This frequency of occurrence is a better measure of distribution within a subsample than is cover since it tends to be independent of plant size and dominance.

The parts of the Reserve not included in the quantitatively measured associations, such as the valley-bottoms and stands of pure *Dicranopteris* on steep slopes, were examined with long walking transects or jeep traverses resulting in species lists on which the only notations were of observational frequency, dominance, age, size, and general habitat and distribution.

Species Distribution

From the transect data in TABLE II and the general reconnaissance of the much wider area, including other ridges, the valley bottoms, and the higher elevations of the study site, it is possible to arrange the vegetation into three distinct and more or less homogeneous plant communities. The first and most general of these is the *Setaria–Paspalum* (weedy grass–shrub) association on the ridge-tops and exposed south slopes. On the northeast slopes extending nearly to the bottoms and occupying the northeast edge of the ridge is a community of weedy grasses and ferns designated as *Setaria–Nephrolepis* association. In the valley-bottom, a riparian, or at least much more mesic association of small trees, ferns and associated species is found. None of these communities approaches a climax type and each of them is a degraded representation of a collection of introduced species, each on a different habitat type.

The *Setaria–Paspalum* association of the ridge-top is a common one in the high-rainfall zone in the Hawaiian Islands and is similar to the vegetation associated with another known bauxite area on Maui (Haiku). As shown in TABLE II, this association is dominated by several common weedy grasses, *Setaria geniculata, Paspalum orbiculare,* and herbs such

TABLE II. Mean Cover and Frequency Percentage in Two Associations on Gibbsitic Soils of Kauai.

SPECIES	ASSOCIATIONS			
	SETARIA–PASPALUM (13 transects)		SETARIA–NEPHROLEPIS (4 transects)	
	Cover	Frequency	Cover	Frequency
Grasses				
Setaria geniculata	62%	99%	82%	99%
Paspalum orbiculare	38	82	20	58
Sacciolepis contracta	17	58	30	71
Chrysopogon aciculatus	7	21	2	6
Paspalum conjugatum	6	17	1	3
Ferns				
Nephrolepis exaltata	0	0	30	56
Stenoloma chinensis	5	14	14	34
Sadleria cyatheoides	0	0	2	4
Pteridium aquilinum	0.4	0.4	1	4
Shrubs				
Stachytarpheta cayennensis	12	50	18	61
Psidium guajava	1	4	2	7
Lantana camara	5	11	5	14
Eugenia cumini	4	5	0	0
Melastoma malabathricum	1	1	12	25
Psidium cattleianum	1	2	0.5	1
Herbs				
Elephantopus mollis	26	63	2	5
Centella asiatica	4	36	11	56
Cassia leschenaultiana	1	16	2	34
Spathoglottis plicata	5	14	4	13
Mimosa pudica	2	6	0	0
Passiflora foetida	1	6	0.5	2
Cuphea carthagenensis	1	4	0.5	2

as *Stachytarpheta cayennensis* (joee) and *Elephantopus mollis*, a declared noxious weed (FIG. 5). Also represented in the community with a high degree of constancy are *Paspalum conjugatum*, *Centella asiatica*, *Lantana camara*, *Cassia leschenaultiana*, *Sacciolepis contracta*, and the Philippine ground orchid, *Spathoglottis plicata*. All are introduced species and of no agricultural value except for the low grazing value of the dominant grasses. The one possibly indigenous species, *Chrysopogon aciculatus* (pilipiliula), has value as a soil binder and appears on about half the plots in the association, usually on very dry, exposed, and partially eroded areas. This is considered a true pioneering species in the successional trend following disturbance.

The habitat occupied by this association is the driest of the three described, but it still receives in excess of 80 inches of precipitation annually. It includes the ridge-top where an unimproved road was clearly marked by the growth of *Sporobolus capensis* and *Axonopus affinis* (FIG. 1), and the southwest-facing slope where the *Eugenia cumini* (Java plum) was found among the planted cultivars of *Macadamia, Araucaria*, and *Pandanus*. This association occupied one-half or more of the area of any given ridge in the Game Refuge.

The second association, *Setaria–Nephrolepis* (grass–fern), is slightly less extensive and occupies the northeast-facing slopes and the north sides of the ridges (FIG. 2). This area (about one-third of the total) is dominated by the same two weedy grasses: *Setaria geniculata* and *Paspalum orbiculare*. It is also well supplied with *Stachytarpheta* (TABLE II), *Centella, Cassia, Sacciolepis contracta*, and the *Spathoglottis*. *Paspalum conjugatum, Chrysopogon aciculatus*, and *Elephantopus* are much less common, but there is a substantial degree of dominance of the *Nephrolepis exaltata* and *Stenoloma chinensis*, the lace fern. The smaller Hawaiian tree fern or amaumau, *Sadleria cyatheoides*, also occurs. The noxious weedy shrub *Rhodomyrtus tomentosa* was gaining a foot-hold on this area at the time of first examination, spreading from its focus of introduction near the Kilohana Crater into favorable habitats at even greater distances. *Metrosideros* growth is vigorous in this habitat and given enough time without disturbance would eventually dominate even the *Melastoma* in most of the situations observed. Older specimens of *Metrosideros* show a marked production of aerial roots which apparently is associated with high moisture and favorable growing conditions. It should be pointed out that, in this instance, the combination of steep slope and its position athwart the northeast trade winds is thought to be responsible for the more mesic environment in this habitat type and *not*, as in more temperate climates, the protection of the north and east slopes from the effects of direct insolation, although this may play a minor role here also.

In the lower edge of this *Setaria–Nephrolepis* association there are frequent occurrences of solid stands of *Dicranopteris linearis*, the false staghorn fern (FIG. 3). *Dicranopteris* (*Gleichenia*) has been recognized as an accumulator of aluminum by several authors and has been analyzed in Hawaii (Moomaw *et al.*, 1959) where it was found to contain consistently high concentrations of aluminum. In addition to its relation to the aluminum levels in soils, *Dicranopteris* is usually associated with a mesic environment, as are most ferns. In this case the fern communities occur on the lower slopes of the ridges just above the valley-bottoms. Since free flowing water is observed in the valleys most of the year, it may be inferred that the hydrology of the area is such that the false staghorn patches coincide with the area of effluence of ground water leaching through the upper aluminous horizons. The outflow of water may not be great but it is reasonable to expect a water table not far below this level and also to expect that this percolation water is low in dissolved bases and silica and high in aluminum content. In addition, of course, the moist drainage ways and valley bottoms are protected from the fires that have swept the ridges at frequent intervals.

The plant association in the wooded valley-bottom (FIG. 4) was not examined quantitatively as were the upper areas on the aluminous soils but a thorough reconnaissance and collection was made. This semi-riparian community is dominated at present by an overstory of *Psidium guajava* (guava) with an occasional specimen of *Pandanus odoratissimus*, *Eugenia malaccensis* (mountain apple) and *Aleurites moluccana* (candle-nut tree). The latter two species show vigorous signs of reproduction in the understory and many fallen logs indicate the former importance of these trees in the community. The trees and rocks in this moist habitat support a number of epiphytic species of lichens, mosses, liverworts, and ferns as well as climbing vascular plants. The ground cover as well, is made up of ferns in especially moist places, the dominant or frequently occurring species are *Phlebodium aureum*, *Elaphoglossum reticulatum*, *Athyrium microphyllum*, *Dryopteris dentata*, *Blechnum occidentale*, and others. The lianes include a native *Peperomia* and *Dioscorea bulbifera*. The *Zingiber zerumbet* (awa'puhi), a *Lobelia*, and *Sida acuta* occur with some regularity, and, in places where drainage is good, the ground is covered with *Oplismenus hirtellus* (basket grass) in the open shade of the dominant guava. In more moist situations, the sedges, *Cyperus alternifolius* and *Cladium meyenii*, are frequent unless completely shaded by the *Hibiscus tiliaceus* (hau tree) or unless permanent water favors a semiaquatic community with rushes, *Jussiaea suffruticosa* var. *ligustrifolia*, and *Dryopteris gongylodes*.

Effects of Fire

During the course of the studies of the Kauai bauxite area, an excellent opportunity was afforded to study the effects of fire when the Territorial Division of Fish and Game embarked on a program of burning the area adjacent to the study site in an attempt to improve the cover and food supply for game birds. Most of the area within the Game Reserve was burned over a period of months beginning in December, 1958. This was eight months after the initial vegetation examination and after eight months following the burn, a reëxamination was made of some of the same transects. The results of this detailed examination are shown in TABLE III where the kind and degree of change is shown as a "consensus" of the five transects examined.

The more marked effects of fire, eight months following the burn are the increase in some of the broad-leaved weeds, the decrease in cover of the woody plants and *Stenoloma*, and the predictable reduction in litter and organic matter on the surface of the soil (or increase in bare soil cover) (FIG. 5). Principal increasers were *Elephantopus mollis*, *Cassia leschenaultiana*, *Cuphea carthagenensis*, *Chrysopogon aciculatus*, *Emilia sonchifolia*, and *Pteridium aquilinum*. Of these, the change in *Emilia* was the most striking, since its presence was not noted at the time of the first

TABLE III. **Comparative Cover of Major Species in Two Associations on Gibbsitic Soils of Kauai Before and After Fire.**

SPECIES	ASSOCIATIONS					
	SETARIA–PASPALUM (3 transects)			SETARIA–NEPHROLEPIS (2 transects)		
	Before Fire		After Fire	Before Fire		After Fire
Grasses						
Setaria geniculata	78%	>	60% *	84%	>	64%
Paspalum orbiculare	27	=	32	25	=	29
Sacciolepis contracta	11	=	14	27	=	28
Chrysopogon aciculatus	9	<	20	2	=	2
Paspalum conjugatum	6	>	0.3	0	=	1
Ferns						
Nephrolepis exaltata	0	=	0	6	=	6
Stenoloma chinensis	4	>	0	2	>	0
Pteridium aquilinum	0	=	1	1	<	3
Shrubs						
Stachytarpheta cayennensis	15	=	15	24	=	26
Psidium guajava	0	=	2	4	=	4
Lantana camara	9	>	3	8	=	7
Melastoma malabathricum	4	>	0	8	>	3
Psidium cattleianum	5	>	0.1	0	=	1
Herbs						
Elephantopus mollis	32	=	31	2	=	4
Centella asiatica	3	=	5	10	=	8
Cassia leschenaultiana	1	<	5	1	<	4
Spathoglottis plicata	5	>	1	5	=	4
Passiflora foetida	1	=	1	1	=	1
Cuphea carthagenensis	0	=	1	1	<	4
Emilia sonchifolia	0	<	5	0	<	2
Bare soil	0	<	12	0	<	12

* **Trends:** >, decrease; <, increase; =, no change.

examination except as a casual occasional plant on disturbed areas. The increase in *Elephantopus* is not impressive, partly because of the biennial habit of the plant and partly because the change was more pronounced in the more moist *Setaria–Nephrolepis* habitat type. Not all the plants appeared to be of biennial habit since some had flowered at the time of examination. The increase of *Cassia* following fire is large and involves both numbers of plants and size of individuals. It is possible that a slight seasonal effect tends to reinforce this difference. *Cuphea* was only mildly stimulated by the burning. *Chrysopogon* has been observed to thrive on the exposed and eroded south slopes and was predictably improved in its competitive position by fire. *Passiflora foetida* increased slightly in frequency in both associations.

Species showing a strong tendency to decrease in cover or frequency following fire in the two associations studied were *Lantana camara*, *Stenoloma chinensis*, *Melastoma malabathricum* (FIG. 6), and *Paspalum conjugatum*. To a lesser degree, *Spathoglottis plicata* showed a decrease in frequency while *Setaria geniculata* declined in cover only. *Stenoloma* was completely obliterated by the fire in places where it had been recorded a year before, while the woody *Lantana* and *Melastoma* were markedly reduced in cover but observation revealed that they were by no means killed.

Species that were little affected by burning include guava, which was found only in the *Setaria–Nephrolepis* community and which was observed elsewhere to be severely damaged by fire, *Centella asiatica*, *Sacciolepis contracta*, *Paspalum orbiculare*, and *Stachytarpheta cayennensis* which increased much less than expected.

Following the simulated strip-mining and planting of the stripped aiea with forage, field and fruit crops, a number of species new to the area were observed. An inventory of plants new to this area and appearing in the disturbed areas was taken and these are designated as "invaders" in the APPENDIX. Since all the fruit and ornamental plants were brought in from elsewhere, some as potted plants, undoubtedly some of the invaders came in with the plants. Others such as *Solanum nigrum* (popolo) may have already been in the soil in dormant condition awaiting proper conditions before breaking their dormancy and making their appearance. Stripping, followed by field preparation, apparently supplied the necessary conditions for the germination of long dormant seeds.

SUMMARY AND CONCLUSIONS

The evidence from the present study points to conclusions similar to those from the Jamaican study of Howard and Proctor (1957) in that none of the species studied shows a definite affinity for ecologic niches characterized by high aluminum content of the soil. The species present are nearly all those adapted to a generally moist environment with warm equable temperatures, acid, infertile soils, and a shallow root zone. Since the aluminum content of the soil increases with depth while the rooting of the dominant plants is unusually shallow, it must be inferred that they are not dependent on high levels of aluminum for survival, but rather are restricted in their root development to the organic and more fertile upper horizons. In addition, the major changes in the vegetation pattern apparently are not governed by alterations in the soil profile, but rather are related to slope, exposure and effective rainfall. The high degree of disturbance of the natural pattern through fire, grazing and manipulation of the cover has further removed the expression of the natural vegetation determinants. Despite the fact that several of the species encountered are known to contain high levels of aluminum (*Dicranopteris linearis, Paspalum orbiculare, Melastoma malabathricum* and sometimes *Nephrolepis exaltata*) and are growing on soils classed as aluminous, it can only be said that they are tolerant of the condition and are capable of accumulating the aluminum ion.

The most important single factor in the present distribution of species in the area is the locus and date of introduction of each of them and their competitive relationship both to the endemic species which they have replaced and to each other. A tabulation of the species present reveals only 5% to be endemics, while 30% are indigenous species of fairly wide Island distribution (see species list), and the remainder are introductions. The indigenous and endemic species occur more frequently in the gulch bottoms and protected areas than on the exposed and disturbed slopes and ridges, clearly indicating their remnant nature.

Other vegetation anomalies, such as the presence of *Scaevola frutescens* (beach naupaka) and other invaders, can be attributed to the importation of sand, coral and cinders at various times for road and building purposes.

Few of the species in the initial stages of succession on the Jamaican bauxites are the same as those observed on the Kauai site, but the later, more persistent weedy plants include *Lantana*, *Stachytarpheta*, and *Sida* which were present in Jamaica also. Several of the grasses used for revegetation in Jamaica are the same ones favored in the Wailua Reserve, such as *Digitaria decumbens* (Pangola grass), *Melinis minutiflora* (molasses grass), and *Panicum purpurascens* (Para grass). *Panicum maximum* (Guinea grass) was useful in the Jamaican study, while the site on Kauai was considered too wet for the successful establishment of any large-scale planting of Guinea grass. The overburden removed from the mining sites was observed to be unusually fertile in Jamaica, as it was in Hawaii, partly owing to the high content of organic matter and partly owing to the content of weed seeds, roots and living plant parts.

Studies with the major plantation and pasture crops in Hawaii have shown that successful production can be attained with applications of fertilizer in fairly large amounts. Six to eight hundred pounds per acre of complete fertilizer, with or without lime, will give good results with *Digitaria decumbens* and *Desmodium intortum* on either the mined substrate or the returned topsoil and produce a rapid vegetative cover. Sugar cane and pineapple can be grown at plantation levels of production or above, if well fertilized.

REFERENCES CITED

Braun-Blanquet, J. 1932. The study of plant communities. McGraw-Hill Book Co.

Brown, D. 1954. Methods of surveying and measuring vegetation. Comm. Bur. Past. and Field Crops Bull. **42.**

Chenery, E. M. 1948. Aluminium in the plant world. Kew Bull. **1948:** 163–173.

———. 1949. Aluminium in the plant world. *Ibid.* **1949:** 433–466.

Cline, M. G., *et al.* 1955. Soil survey of the Territory of Hawaii. U. S. D. A. Soil Survey Series 1939, No. **25.**

CROCKER, R. 1952. Soil genesis and pedogenic factors. Quart. Rev. Biol. 27(2): 139–168.

DEGENER, O. 1932–date. Flora Hawaiiensis **1–5.** Published by the author.

HOWARD, R. A., and PROCTOR, G. R. 1957. The vegetation on bauxitic soils in Jamaica. Jour. Arnold Arb. **38:** 1–41, 151–169.

MACDONALD, G. A., DAVIS, D. A. and COX, D. C. 1954. Kauai, an ancient Hawaiian volcano. Volcano Letter No. **526:** 1–3.

MOHR, E. C. J., and VAN BAREN, F. A. 1954. Tropical soils. Interscience Publishers Inc.

MOOMAW, J. C., NAKAMURA, M. and SHERMAN, G. D. 1959. Aluminum in some Hawaiian plants. Pacific Science **13:** 335–341.

NEAL, MARIE C. 1948. In gardens of Hawaii. B. P. Bishop Museum Spec. Publ. **40.**

RIPPERTON, J. C., and HOSAKA, E. Y. 1942. Vegetation zones of Hawaii. Hawaii Agr. Exp. Sta. Bull. **89.**

SHERMAN, G. 1958. Gibbsite-rich soils of the Hawaiian Islands. Hawaii Agr. Exp. Sta. Bull. **116.**

———, and KANEHIRO, Y. 1948. The chemical composition of Hawaiian forest floors. Hawaii Agr. Exp. Sta. Bien. Rep. **1946–48.**

WEATHER BUREAU. 1959. Hawaii, annual summary, 1958. Climatological data **54**(13): 154–160.

WEBB, L. J. 1954. Aluminium accumulation in the Australian–New Guinea flora. Austr. Jour. Bot. **2:** 176–196.

EXPLANATION OF PLATES

PLATE I

FIG. 1. The *Setaria–Paspalum* association of the ridge-top, Wailua Game Refuge, Kauai. *Sporobolus capensis* is seen along the roadway. Shrubs in the background include *Eugenia cumini*, *Pandanus odoratissimus*, *Psidium guajava*, and *Melastoma malabathricum*, an aluminum accumulating species. FIG. 2. The *Setaria–Nephrolepis* association on a north-facing slope. The "Ama'uma'u" tree fern, *Sadleria cyatheoides*, is seen in the middleground. *Setaria* and *Paspalum* are the dominant grasses.

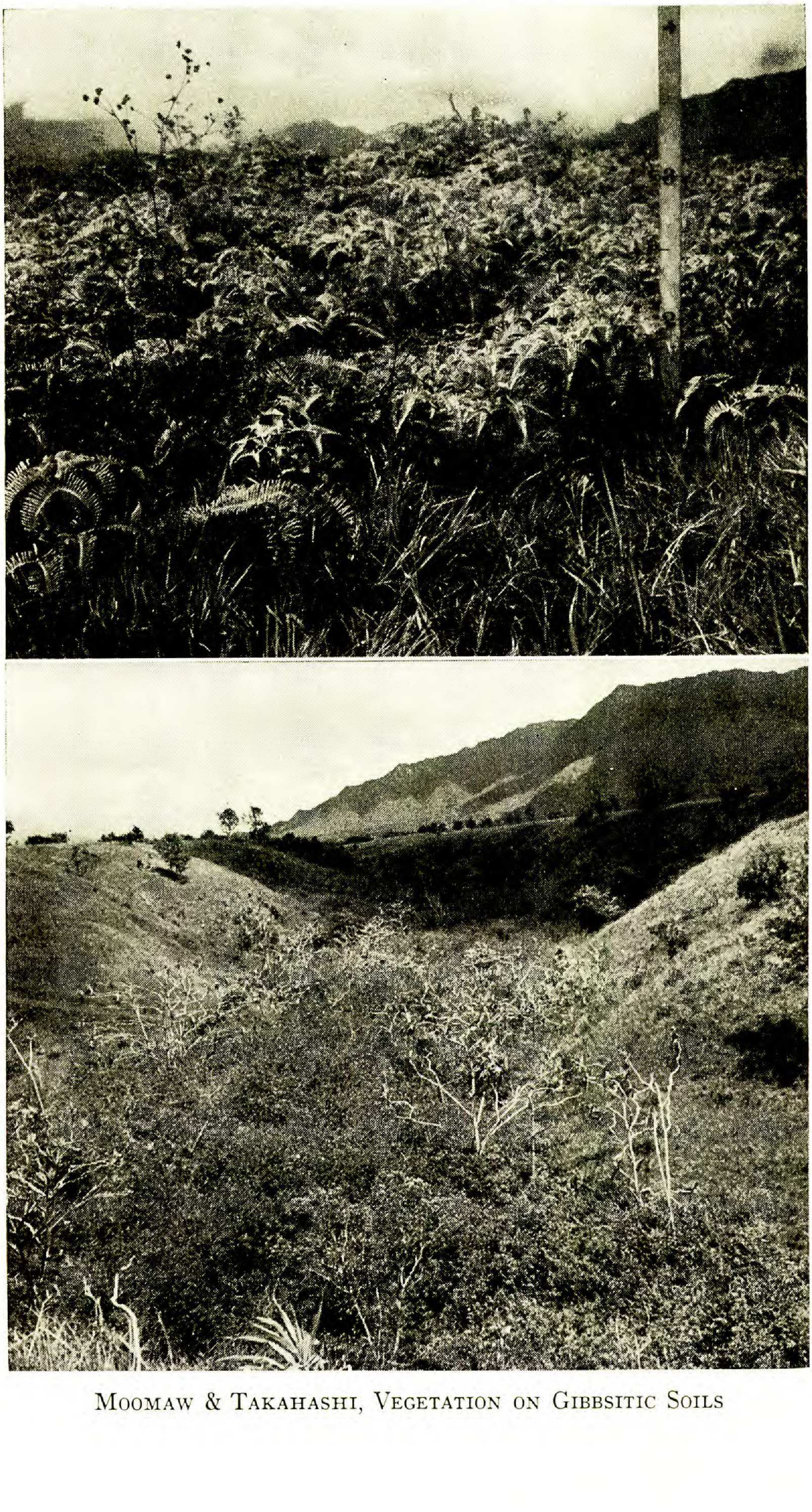
PLATE II

FIG. 3. *Dicranopteris linearis*, known to be an aluminum accumulating fern, occurs primarily on the lower slopes and valley bottoms. FIG. 4. The vegetation of the protected valleys is dominated by *Psidium guajava* and *Pandanus odoratissimus*. The understory contains high percentages of ferns (*Dryopteris*) and *Oplismenus hirtellus*, the shade-tolerant "basket grass." Most of the indigenous species were found in this association.

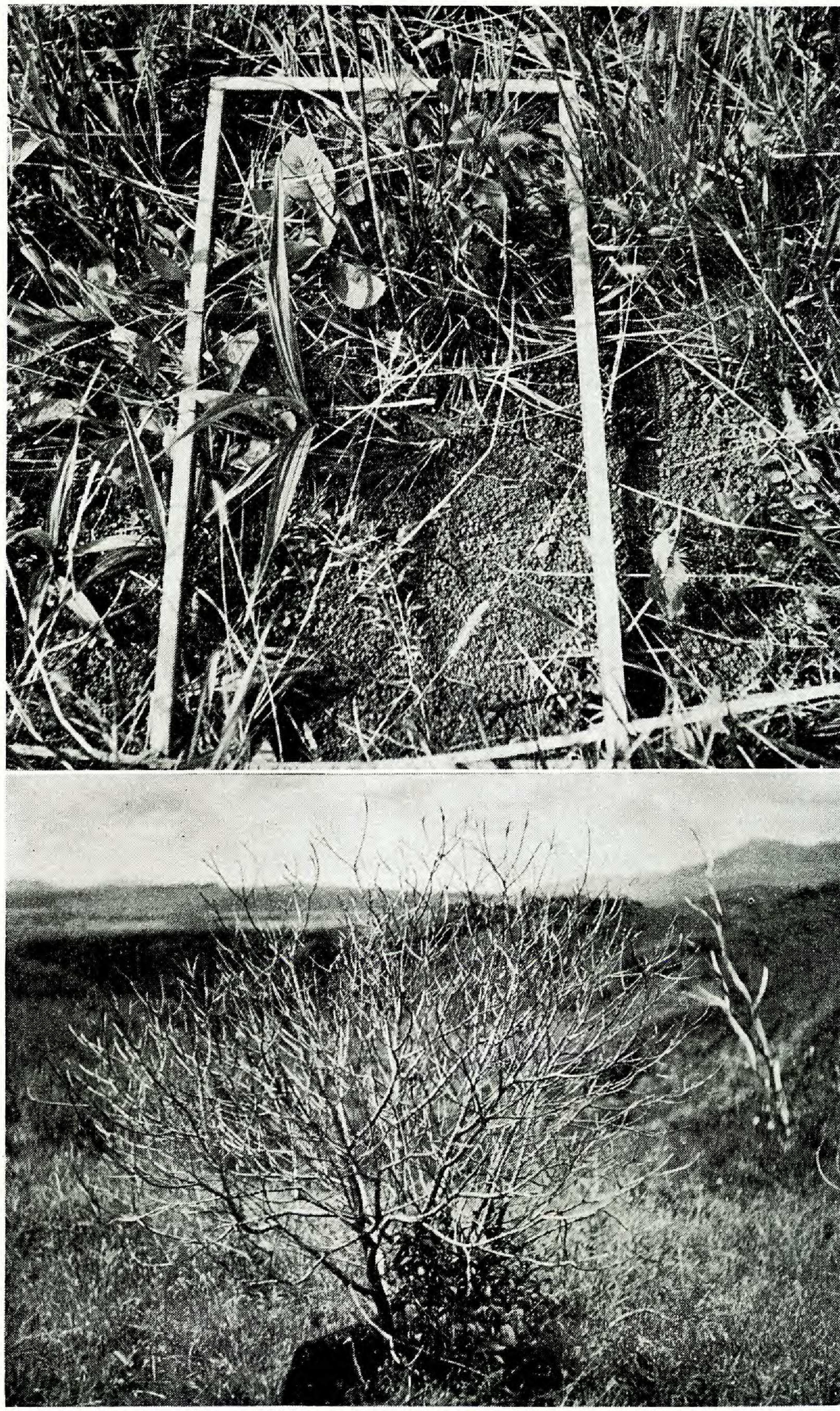
PLATE III

FIG. 5. A plot in the *Setaria–Paspalum* association following fire. A young orchid plant, *Spathoglottis plicata*, occurs on the left side of the plot, while the broad leaves are those of *Elephantopus mollis*. The stoloniferous grass on the bare soil is *Chrysopogon aciculatus*. FIG. 6. Regeneration of *Melastoma malabathricum* six months following fire. Top growth is completely killed back. Note that the *Setaria* has already produced mature inflorescences.

MOOMAW & TAKAHASHI, VEGETATION ON GIBBSITIC SOILS



MOOMAW & TAKAHASHI, VEGETATION ON GIBBSITIC SOILS



MOOMAW & TAKAHASHI, VEGETATION ON GIBBSITIC SOILS

APPENDIX. **Species List with Occurrence and Origin Indicated.**

Symbols: A, abundant; C, common; U, uncommon; R, rare; I, indigenous; E, endemic; *, known in Hawaii at that date; P, planted (usually by Board of Agriculture and Forestry); +, invader of stockpiled topsoil or of exposed subsoil.

SPECIES	OCCURRENCE			ORIGIN	
	RIDGE	SLOPE	VALLEY	INDIGENOUS OR ENDEMIC	INTRODUCED
FERNS AND FERN ALLIES					
Asplenium insiticium			U	?	
Athyrium microphyllum			U	?	
Blechnum occidentale			U		1923 Trop. Am.*
Cibotium chamissoi		U	U	E	
Dicranopteris linearis		C		I	
Diplazium sandwichianum			R	E	
Dryopteris dentata			C	I	
Dryopteris gongylodes			R	?	
Elaphoglossum reticulatum			U	E	
Lycopodium cernuum		U		I	
Microlepia setosa			U	I	
Microsorium scolopendria			U	?	
Nephrolepis biserrata var. *furcans*		U	U	I	
Nephrolepis exaltata	C	A	U	I	Pantropic
Nephrolepis hirsutula		R		I	
Phlebodium aureum			U		Trop. Am.
Pleuropeltis thunbergiana			U	I	
Psilotum nudum	U	U		I	
Pteridium aquilinum var. *decompositum*	U	U		I	
Sadleria cyatheoides	?	U		I	
Stenoloma chinensis	C	C		I	
GYMNOSPERMAE					
Araucariaceae					
Araucaria excelsa	U				P, Norfolk Island
MONOCOTYLEDONEAE					
Araceae					
Colocasia esculenta			U	I	
Commelinaceae					
Commelina diffusa			C		1888, Pantropic *
Cyperaceae					
Carex sp.	U			?	
Cladium meyenii			U	?	
Cyperus cylindrostachyus			U		1898, Madagascar *
Cyperus kyllingia f. *humilis*	U				1900, Pantropic *
Cyperus rotundus	C				+ 1850 *
Fimbristylis diphylla		U	U		Widespread

Species List (*Continued*)

SPECIES	OCCURRENCE			ORIGIN	
	Ridge	Slope	Valley	Indigenous or Endemic	Introduced
Rhynchospora lavarum			R	E	
Scirpus validus			U		1888, N. Am.*
Dioscoreaceae					
Dioscorea bulbifera			R	I	
Gramineae					
Axonopus affinis	C	C			1912, Trop. Am.
Chloris inflata	U				+ 1906, Trop. Am.*
Chrysopogon aciculatus	U	C		I	
Coix lacryma-jobi			U		1888, Indonesia *
Cynodon dactylon	U				+ 1835, Old World *
Digitaria henryi	U				1932, Formosa
Digitaria violascens	U				+ 1917, Trop. Asia
Eleusine indica	U				+ 1840, India *
Oplismenus hirtellus			C		1841, Trop. Am.
Panicum purpurascens			U		1902, Africa
Paspalum conjugatum	C	C	C		1840, Dutch Guiana*
Paspalum orbiculare	A	A	U		1888 Asia *
Paspalum urvillei	U				1906, S. Am.
Sacciolepis contracta	C	A			+ 1906, Indonesia
Setaria geniculata	A	A			1851, Europe *
Setaria verticellata	U				+ 1860, Europe *
Sporobolus capensis	U				1903, Africa
Liliaceae					
Cordyline terminalis		U		I	
Orchidaceae					
Spathoglottis plicata	C	C			? Asia–Malaya
Pandanaceae					
Freycinetia arborea			U	E	
Pandanus odoratissimus		C	C	I	
Pandanus variegatus		U			P
Taccaceae					
Tacca leontopetaloides			U	I	
Zingiberaceae					
Zingiber zerumbet		U	U	I	India
DICOTYLEDONEAE					
Amaranthaceae					
Amaranthus hybridus	U			I	+ Pantropic
Amaranthus spinosus	U				+ 1900, Trop. Am.
Amaranthus viridus	U				+ Trop. Am.
Anacardiaceae					
Schinus terebinthifolius	U				+ 1917, S. Am.
Caryophyllaceae					
Drymaria cordata			U		1900, Asia–Malaya

Species List (*Continued*)

SPECIES	OCCURRENCE			ORIGIN	
	Ridge	Slope	Valley	Indigenous or Endemic	Introduced
Casuarinaceae					
Casuarina equisetifolia		U			P 1895, Malaya
Convolvulaceae					
Ipomea pes-caprae	R			I	+
Compositae					
Bidens pilosa	U				+ 1864, Trop. Am.*
Eclipta prostrata	U				Widespread
Elephantopus mollis	A	A	C		+ 1931, Trop. Am.
Emilia sonchifolia	C				+ Trop. Asia
Erechtites valerianifolia	U				+ 1870, N. Am.
Erigeron canadensis	C	R			+ ? N. Am.
Pluchea odorata	U				1931, S. Am.*
Sonchus oleraceus	U				? Europe
Vernonia cinerea	U				+ Trop. Afr., Asia
Euphorbiaceae					
Aleurites moluccana			U	I	
Euphorbia hirta	U				+ 1888, Pantropic *
Euphorbia hypericifolia	U				+ Pantropic
Euphorbia thymifolia	U				+ Widespread
Goodeniaceae					
Scaevola frutescens var. *sericea*	U	U		I	
Scaevola gaudichaudiana	U	U		I	
Lauraceae					
Cinnamomum camphora	R				? China
Leguminosae					
Albizzia moluccana		U			1917, Malaya
Cajanus cajan	U				P 1909, India
Canavalia sericea			U	I	
Cassia leschenaultiana	C	C			1888, India *
Crotalaria incana	U				+ Trop. Am.
Desmodium canum	U				P 1916, Trop. Am.*
Desmodium uncinatum	R				Trop. Am.
Mimosa pudica	C	C			1800, Trop. Am.*
Vigna marina			U		Pantropic
Lobeliaceae					
Lobelia sp.			R	E	
Lythraceae					
Cuphea carthagenensis	C				+ 1900, Trop. Am.
Malvaceae					
Hibiscus tiliaceus	U	U	C	?	?
Sida acuta		U			?
Melastomaceae					
Melastoma malabathricum	C	C			1916, India

Species List (*Continued*)

SPECIES	OCCURRENCE			ORIGIN	
	Ridge	Slope	Valley	Indigenous or Endemic	Introduced
Myrtaceae					
Eugenia cumini	U	C			1866, Trop. Afr.
Eugenia malaccensis			U		
Metrosideros collina subsp. *polymorpha*	U	C		E	
Psidium cattleianum	C	U			P
Psidium cattleianum f. *lucidum*	U				1888, Trop. Am.*
Psidium guajava	C	C	A		1800, S. Am.*
Rhodomyrtus tomentosa	C	C			1920, Asia
Onagraceae					
Jussiaea suffruticosa var. *ligustrifolia*			U		1888 Pantropic *
Oxalidaceae					
Oxalis corniculatus	U				1888, N. Am.*
Passifloraceae					
Passiflora edulis	U	U	U		1880, S. Am.
Passiflora foetida var. *gossypifolia*	U	U			1888, Trop. Am.
Phytolaccaceae					
Phytolacca acinosa	U				+ Asia
Piperaceae					
Peperomia membranacea var. *waimeana*			R	E	
Portulacaceae					
Portulaca oleracea	U				+ 1888, Pantropic *
Primulaceae					
Anagallis arvensis	U				+ Europe
Proteaceae					
Grevillea robusta	U	U			Australia
Macadamia ternifolia		U			P 1890, Australia
Rubiaceae					
Richardia scabra	R				1888 Trop. Am.*
Solanaceae					
Solanum nigrum	R			?	+
Sterculiaceae					
Waltheria americana		U			1819, Trop. Am.*
Umbelliferae					
Centella asiatica	C	C			1888, Asia *
Verbenaceae					
Lantana camara	C	A	U		1858, Trop. Am.
Stachytarpheta cayennensis	A	A			Trop. Am.